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Marine hermit crabs as indicators of freshwater inundation on tropical shores

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Abstract

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The marine hermit crabs, *Clibanarius taeniatus* (H. Milne-Edwards, 1848) and *C. virescens* (Krauss, 1843) are common rocky intertidal species along the coast of Queensland, Australia. Laboratory experiments in dilute (8‰) seawater at 15°, 25° and 35°C over an extended period (up to 77 h) showed that *C. taeniatus* had significantly better survival than *C. virescens*. In extended exposure to a low salinity, estuarine environment *C. taeniatus* also survived significantly better than *C. virescens*. Repeated sampling at selected sites revealed that a site with no freshwater influence maintained a low percentage of *C. taeniatus* and high percentage of *C. virescens*, while at a site influenced by regular, low level freshwater runoff, the percentage of *C. taeniatus* remained high. A survey of the Queensland coast, showed that *C. virescens* tended to be more dominant on open coasts uninfluenced by freshwater, while *C. taeniatus* tended to be more abundant in areas influenced by freshwater. These two species therefore are a convenient indicator system for the influence of freshwater on tropical intertidal rocky shores and may therefore constitute an important management tool in areas experiencing coastal development with concomitant storm water runoff into marine habitats.

Keywords Crustacea, Anomura, hermit crab, Diogenidae, *Clibanarius taeniatus, Clibanarius virescens*, salinity, tropical, temperature

Introduction

Intense coastal development that has been typical of temperate regions, is now increasing in the tropical regions of the globe (Johannes and Betzer, 1975; Vernberg, 1981). Coastal development can result in a range of pollutants being discharged into coastal habitats. Examples are untreated, or partially treated sewage, chemical effluent from a variety of industrial sources and storm water runoff from residential areas. This last source of pollution is of increasing importance in tropical areas experiencing extensive residential development in the coastal zone. Many tropical areas are subject to episodes of heavy rainfall. It is well known that during floods, unusually large volumes of freshwater runoff from rivers can have severe impacts on marine habitats, particularly intertidal habitats (Goodbody, 1961; Fotheringham, 1975; Coates, 1992; Forbes and Cyrus, 1992; Van Woesik et al., 1995). Thus, fresh water itself may act as a pollutant in the sense of having detrimental effects on marine habitats. Artificial drainage systems tend to concentrate storm water runoff from residential areas into a few points. Storm water drains can cause episodic inundation by fresh water, lasting for several days or weeks, in areas that would not normally experience freshwater runoff, or would experience it only rarely. A convenient indicator system able to detect effects of episodic freshwater runoff into marine habitats would be useful in assessing the impacts of installations such as storm water drains.

Ward (2000: 436) defined environmental indicators as "measurable variables that track changes in important elements, functions or issues in the environment, uses of natural resources, or management of the environment." Indicators should be simple, direct and easy to interpret if they are to be used in large scale reporting (Ward, 2000). Further, an indicator needs to be specific to the type of pollution concerned. There is a long history of the use of marine invertebrates as indicators of the presence and intensity of pollution (Reish, 1972). For example, an increase in the abundance of the polychaete *Capitella capitata* (Fabricius, 1780) has been shown to indicate pollution (probably increased nitrates and phosphates) from domestic outfalls (Filice, 1954; Kitamori and Funae, 1959, 1960; Reish, 1959; Kitamori, 1963; Bellan, 1967). Imposex in marine gastropods is an indicator of the antifouling agent Tributyltin (Bright and Ellis, 1989; Stickle et al., 1990; Nias, 1991; Nias et al., 1993). Filter feeding oysters and mussels are often used as indicators of lipid-soluble pollutants

in the marine environment (Riedel et al., 1995; Chen et al., 1996; Al-Madfa et al., 1998).

Hermit crabs are common in tropical intertidal areas of the world and occupy the empty shells of marine gastropods (e.g. Ball and Haig, 1974; Fotheringham, 1975; Abrams, 1981; Gherardi, 1990; Gherardi and Nardone, 1997; Barnes, 1997). However, unlike the original gastropod owner of the shell, they are unable to completely seal off the aperture of the shell in times of environmental stress, such as dilution of seawater by fresh water. These factors may make hermit crabs better indicators of changes occurring in intertidal conditions and community structures than snails, clams and oysters which can temporarily seal out unfavourable changes in surrounding conditions (Gilles, 1972; Vermeij, 1993; Willmer et al., 2000; and see review by Underwood, 1979). Further, hermit crabs, like many other decapods, tend to have a limited capacity for osmotic regulation. Consequently, they are vulnerable to osmotic stress caused by freshwater inundation resulting in the dilution of sea water. Species, however, may differ in their tolerance to dilution of their blood and body fluids, and therefore, in their survival during episodes of freshwater inundation. It is rather surprising then, that scientific investigations into the use of hermit crabs as indicators of ecological health are limited to a single study by Lyla and Ajmal Khan (1996) who used the estuarine hermit crab, *Clibanarius longitarsus* (De Haan, 1849) as an indicator of changes in heavy metals (iron and manganese) in the Vellar estuary, India, over a period of one year. Lyla et al. (1998) are the only authors, to our knowledge, that have proposed the use of hermit crabs as test organisms for detecting environmental impacts.

Clibanarius taeniatus and *C. virescens* are closely related species of intertidal hermit crabs common to rocky shores of tropical eastern Australia. Preliminary observations indicated that although the two species have overlapping distributions (Dunbar, 2001), *C. virescens* dominates open coast areas not normally influenced by fresh water while *C. taeniatus* was more common in areas influenced by fresh water. The present study was undertaken to document the differences in distribution of the two species and to determine if the species differ in their tolerance of osmotic stress. On the basis of the findings of this study we argue that these two species can serve as an indicator system for the detection of changes that may occur in rocky intertidal environments caused by storm water runoff from residential areas.

Materials and methods

Survival tests. Experiments investigated the survival of *C. taeniatus* and *C. virescens* exposed to dilute sea water at three different temperatures. Hermit crabs were collected from the field and immediately transported to the laboratory where they were kept in aquaria under a 12 h light:12 h dark regime and acclimated in a constant temperature room at 25±2°C in 36‰ sea water for at least 7 days before being exposed to treatment conditions. Individuals were selected for testing without regard to weight or shell type and no effort was made to sex individuals. Individual hermit crabs remained in their original shells throughout the course of the experiments.

Fifteen individuals of each species were randomly selected and individually placed in 250 ml perspex chambers in 50 ml of 8‰ sea water diluted with distilled, deionised water. The 30 test chambers were then placed into a constant temperature water bath to maintain a treatment temperature of 15°, 25° or 35° ± 1.0°C. Controls at each temperature were carried out with 15 individuals of each species in 36‰. At irregular intervals throughout the experiment, hermit crabs were observed for signs of life. Individuals that did not respond to slight chamber shaking or abdominal prodding by movement of the pereopods, antennules or maxillipeds, were considered dead and removed from the chamber. The interval in which each hermit crab died was recorded.

Estuarine translocation. Clibanarius taeniatus and *C. virescens* were collected from a common intertidal area without respect to size, shell species or sex. Crabs were transported to the control and experimental sites in the estuary of the Fitzroy River, Rockhampton in an open container in approximately 2 L of 36‰ water. Upstream treatment sites were chosen that provided prolonged exposure to a range of dilute sea water from 7–13‰. Control sites farther downstream were chosen to provide prolonged exposure to a range of approximately 27–34‰. At the treatment sites chambers made of PVC pipe and containing either six of each species, or 12 of one species of variable size, shell species and sex were randomly assigned to seven concrete blocks. Each block had three chambers attached to it. Chambers were kept just below the surface of the water by securing them to the top one metre of a length of rope tied to a concrete block on one end, and a Styrofoam buoy on the other. Hermit crabs were exposed to experimental conditions for 48 h (repetition 1) and 28 h (repetition 2). The time of exposure for repetition 2 was reduced in an effort to increase the number of animals surviving. The total number of chambers initially established for the two repetitions was 42, however, seven chambers were lost during the course of the experiment. At the control site, four blocks with three chambers each were initially established as for the treatment sites, giving 12 control chambers. One control chamber was lost during the experiment.

Upon retrieval of the chambers, each group of crabs was placed in a bath of 36‰ sea water and given approximately 3 min to revive. Each individual was inspected for signs of life (as described above). Each hermit crab was used only once. The total number of "Alive" versus "Dead" of both species for the 35 treatment and 11 control replicates was analysed by Chi-squared 2×2 contingency table.

Repeated sampling at selected sites. Two sites within the Woongarra Marine Park in Queensland were selected for repeated sampling.

(1) Hoffmans Rocks (24°50.4′S, 152°28.7′E). This rocky intertidal site is located on an open coast. There are no storm water drains or natural creeks at this site. This site was divided into six sectors and at each sampling time tide pools in each sector were sampled by random collections of between approximately 50 and 200 hermit crabs which were then identified and counted.

(2) Bauer Street (24°48.9′S, 152°28.0′E). At this site a

storm water drain carries freshwater runoff from a natural creek onto a rocky intertidal area. Freshwater flow is continuous but of low volume except at times of heavy local rainfall. A series of tide pools extends from the top of the shore at the opening of the storm water drain to near the bottom of the intertidal area. The total area here was greater than at Hoffmans Rocks, and so was divided into nine sectors and at each sampling time tide pools within each sector were sampled as above. The two sites were sampled on the same days on 20 February and 20 May 2000 and 23 Mar and 24 Jun 2001.

Survey of Queensland coast. Field surveys of 86 rocky intertidal sites were carried out along the coast of Queensland, from Redcliffe (27°15.8´S, 153°06.3´E) to Cape Kimberley (16°16.7´S, 145°29.1´E) between March, 2000 and February, 2001 (Fig. 1). Latitude and longitude were recorded for each site and, where possible, salinity was recorded. An estimation of the influence of freshwater inundation on each site was made on the basis of proximity to rivers, creeks, or storm water drains according to map locations, data on general directions of wind-wave currents and personal observations. At each site, surveys were done at low tide and transects were laid at three different heights corresponding to low, mid-, and high shore at increasing distance from and parallel to the water line. Ten tide pools were sampled along each of these transects and the relative abundances of *C. taeniatus, C. virescens*, other hermit crab species and empty gastropod shells were recorded.

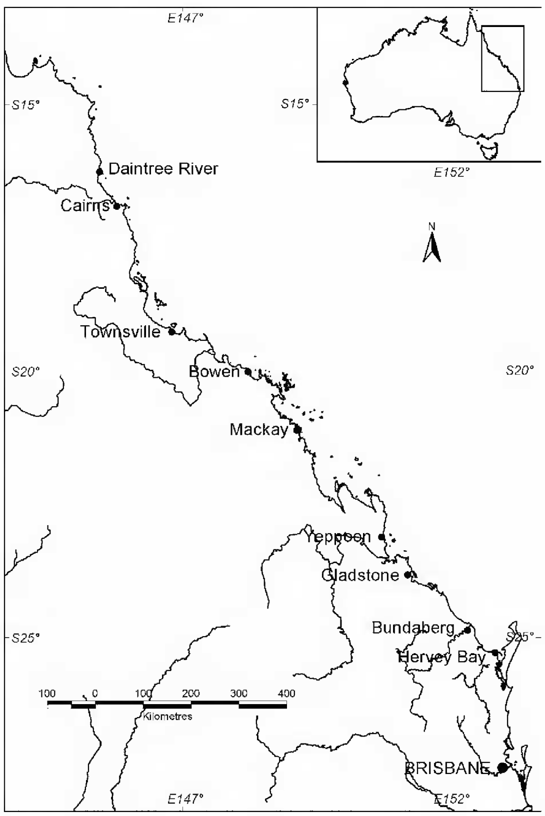

Figure 1. The rocky shore area of Queensland, Australia, covered by the coastal survey. Inset shows the geographical location of this coastal region.

Unfortunately, detailed, continuous sea-water and temperature data were not available for these intertidal sites on the north-eastern coast of Australia. Nevertheless, inshore sea-water temperatures can exceed 30°C during summer in these areas (Fig. 3).

Results

Survival. Figures 2 A, B and C show the survival of the hermit crabs *Clibanarius taeniatus* and *C. virescens* in 8‰ sea water at 15°, 25° and 35°C. From these figures it can be clearly seen that *C. taeniatus* survives significantly better than *C. virescens* in dilute sea water at all three temperatures. Although both species have shortened survival times in dilute sea water at the highest temperature, this was especially detrimental to *C. virescens*. Survival for both species is longest at the acclimation temperature of 25°C. In controls (36‰) at 15° and 25°C both species had 100% survival after 83 and 73 h of exposure, respectively. In 8‰ at 35°C, all *C. virescens* were dead by 16.5 h while 55% of *C. taeniatus* were still alive (Fig. 2 C). In the control at 35°C there was no significant difference in survival between species up to 29 h (χ^2_1=1.88, P>0.05). After 42 h however, *C. taeniatus* had survived significantly better than *C. virescens* (χ^2_1=4.26, P<0.05), although 40% of *C. virescens* were still alive after 78 h (Figure 2 D).

Estuarine translocation. At control sites where water was 27–34‰, there was 100% survival of both species over 48 h of exposure (Table 1). At treatment sites, which were 7–13‰, 30.9% of *C. taeniatus* survived, while only 0.7% of *C. virescens* survived exposure for up to 48 h. These results represented a highly significant difference (χ^2_1= 85.84, P<0.001) in survival between species in favour of *C. taeniatus*.

Table 1. Results from 11 control replicates and 35 treatment replicates of the estuarine environment translocation comparing the proportion surviving between *Clibanarius taeniatus* and *Clibanarius virescens*.

	Alive	Dead	Total
Controls			
C. taeniatus	24	0	24
C. virescens	72	0	72
Treatments			
C. taeniatus	29	65	94
C. virescens	2	298	300

Repeated sampling at selected sites. The results of sampling at Hoffmans Rocks and Bauer Street are summarised in Table 2. At Hoffmans Rocks, with no freshwater influence, the percentage of *C. taeniatus* remained low and *C. virescens* dominated. Although there was some variation among sampling times at Bauer Street, the percentage of *C. taeniatus* remained high at this freshwater influenced site.

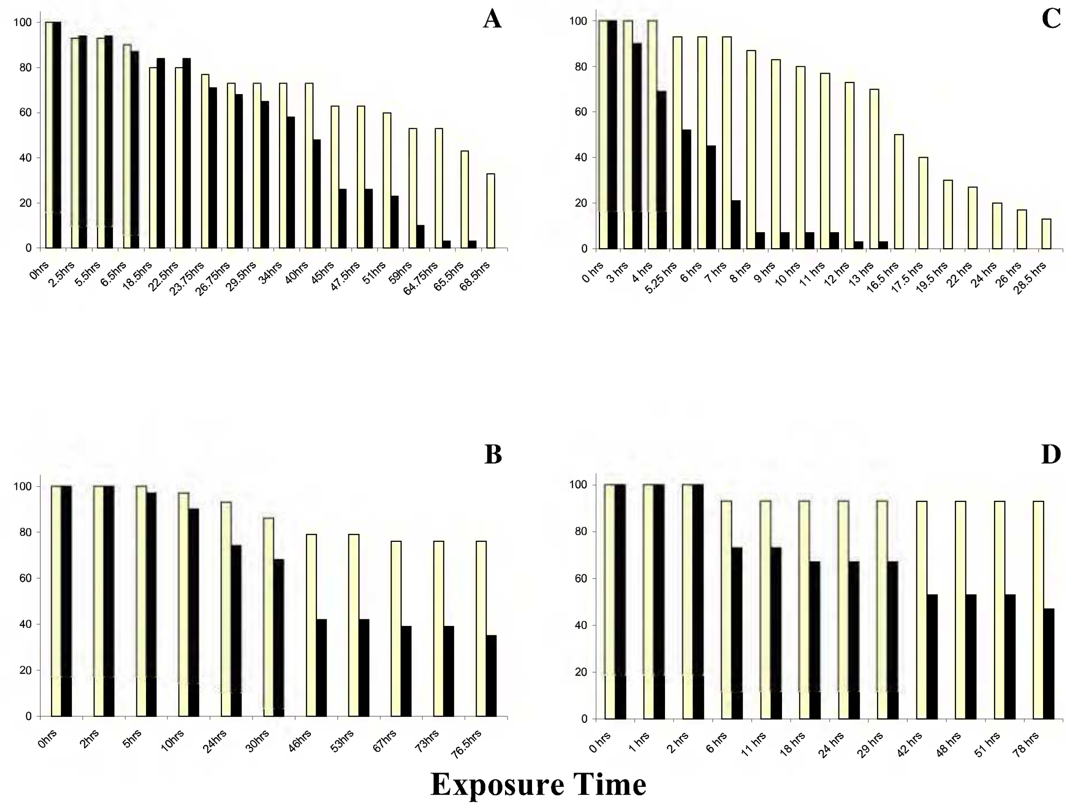

Figure 2. A. Survival of *Clibanarius taeniatus* (shaded bars) and *Clibanarius virescens* (black bars) in 8‰ seawater at 15°C. B. Survival of *Clibanarius taeniatus* (shaded bars) and *Clibanarius virescens* (black bars) in 8‰ sea water at 25°C. C. Survival of *Clibanarius taeniatus* (shaded bars) and *Clibanarius virescens* (black bars) in 8‰ sea water at 35°C. D. Survival of *Clibanarius taeniatus* (shaded bars) and *Clibanarius virescens* (black bars) in 36‰ sea water (control) at 35°C.

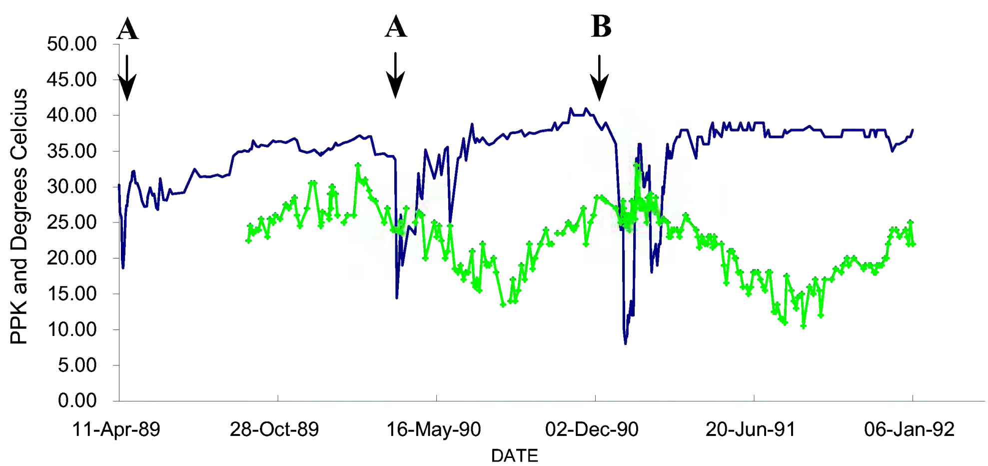

Figure 3. Daily shoreline salinity (dark line) and temperature (shaded line) readings between April, 1989, and January, 1992, along Keppel Bay. Arrows A indicate regular, seasonal flood events on a local scale, arrow B indicates an irregular, flood event on a large, catchment scale. From Coates, unpublished data.

Table 2. Relative abundances (%) of *Clibanarius taeniatus* and *C. virescens* at Hoffmans Rocks and Bauer Street. Survey dates and total sample sizes (N) are indicated.

Survey dates	2000		2001	
	20 Feb	20 May	23 Mar	24 Jun
Hoffmans Rocks				
C. taeniatus	1.8	0.4	3.5	10.1
C. virescens	98.2	99.6	96.5	89.9
N	1092	782	877	307
Bauer Street				
C. taeniatus	47.4	38.3	61.4	55.2
C. virescens	52.6	61.7	38.6	44.8
N	1119	911	1400	1108

Survey of Queensland coast. Field surveys along a section of the Queensland coast (Fig. 1) have demonstrated a differential trend in the distribution of *C. taeniatus* and *C. virescens*. In Table 3 all sites in which *C. taeniatus* and/or *C. virescens* were present have been separated into those sites which are not influenced by fresh water and those which are influenced by fresh water for prolonged periods by rivers, streams, or storm water drains. This table clearly indicates that in areas devoid of freshwater outfalls, such as Conical I., and open coastline sites such as Five Rocks and Double Island Point, the intertidal habitat was completely dominated by *C. virescens* and no *C. taeniatus* were recorded. At sites near rivers, streams, or storm water outfalls, there was a tendency for there to be a reduction in the relative abundance of *C. virescens* and an increase in the relative abundance of *C. taeniatus* (Table 3).

Discussion

Laboratory studies indicated a higher tolerance of *C. taeniatus*, compared to *C. virescens*, to dilute sea water over extended periods of exposure. Survival in dilute sea water was shortest at the highest temperature, but the combination of low salinity and high temperature was especially devastating to *C. virescens*. Prolonged exposure to low salinity in the field resulted in a significant difference in survival in favour of *C. taeniatus*. *Clibanarius virescens* showed a much lower tolerance to low salinity than did *C. taeniatus* in an environment where there was little relief from fresh water. This has significance for tropical coastal zones in the vicinity of freshwater outfalls prone to seasonal flood events. Endean et al. (1956) recognised that there were many rocky sites along the Queensland coast that could be affected by fresh water from nearby river outfalls. Data they obtained indicated that large enough volumes of fresh water were carried by the Burdekin and Fitzroy Rivers, in particular, into their respective bays as to considerably reduce the salinity of nearby coastal waters. They further emphasised that (of the sites they visited) the areas most likely to be affected by river outfall would be Point Vernon, near the Mary River and Yeppoon and Cape Capricorn (Curtis Island), near the Fitzroy River. Their analysis also showed that the majority of rainfall occurs over the summer months, during which time long periods of calm weather in lagoonal areas lead to relatively little mixing and surface salinities that are frequently low. Daily records collected by Coates (unpublished data) showed that shoreline salinity in Keppel Bay (23°23.7′S, 150°53.4′E) was reduced by both local, seasonal flooding (Fig.

Table 3. Relative abundances (%) of *Clibanarius taeniatus* and *C. virescens* at sites along the eastern coast of Queensland, Australia. Sites have been divided into those with no freshwater influence and those influenced by fresh water, and are arranged from south (top) to north (bottom).

Site	Latitude, Longitude	Salinity (‰)	*C. taeniatus*	*C. virescens*
Not Influenced by Fresh Water				
Wickham Pt	26°48.2′S, 153°08.8′E		0	100
Moffat Head	26°47.5′S, 153°08.9′E		0.6	99.4
Pt Cartwright	26°40.7′S, 153°08.3′E		0	100
Alexandra Headlands	26°40.3′S, 153°06.6′E		0	100
Double Island Pt	25°56.2′S, 153°11.3′E		0	100
Woongarra Marine Park	24°50.4′S, 152°28.7′E		7.0	93.0
N Middle Rock	24°17.0′S, 151°57.1′E		0	100
Rocky Pt	24°14.0′S, 151°56.2′E		0	100
Yellow Patch	24°30.4′S, 151°13.3′E	38.2	44.4	55.5
Cape Capricorn (Curtis I.)	23°29.1′S, 151°13.9′E	38.2	0	100
Long Beach (Great Keppel I.)	23°11.6′S, 150°50.8′E		0	100
W. Shellving Bch (Grt Keppel I.)	23°11.3′S, 150°50.6′E		0	100
E. Shellving Bch (Grt Keppel I.)	23°11.2′S, 150°50.6′E		0	100
Conical I.	23°03.3′S, 150°52.7′E		0	100
Five Rocks	22°48.1′S, 150°48.5′E		0.1	99.9
Lamberts Beach	21°03.8′S, 149°13.5′E		19.4	80.6
Pandanas Bay (Long I.)	20°20.4′S, 148°51.0′E		3.3	96.7
Back Beach (Long I.)	20°20.2′S, 148°51.3′E		3.6	96.4
Bauer Bay (S Mole I.)	20°15.6′S, 148°50.1′E		0	100
Horseshoe Bay	19°58.7′S, 148°15.7′E		2.2	97.8
Bingil Bay	17°50.1′S, 146°06.0′E		0	100
Nudey Beach (Fitzroy I.)	16°56.2′S, 145°59.0′E		0	100
N Welcome Bay (Fitzroy I.)	16°55.9′S, 145°59.3′E		0	100
N Ellis Beach	16°42.9′S, 145°39.1′E		0	100
Port Douglas	16°29.1′S, 145°28.2′E	29.9	1.0	99.0
Dayman Pt	16°22.9′S, 145°24.9′E		0	100

Table 3 — Continued.

Site	Latitude, Longitude	Salinity (‰)	*C. taeniatus*	*C. virescens*
Influenced by Fresh Water				
Woody Pt (Moreton Bay)	27°15.8´S, 153°06.3´E		100	0
S Scott Pt (Moreton Bay)	27°15.3´S, 153°06.6´E		100	0
N North Bluff (Big Woody I.)	25°16.4´S, 152°56.8´E		100	0
Datum Pt.(Big Woody I.)	25°16.3´S, 152°56.6´E		100	0
Sandy White Memorial Park.	25°16.3´S, 152°50.0´E		100	0
The Gables (Pt Vernon)	25°14.8´S, 152°49.6´E		100	0
Burrum Heads	25°11.0´S, 152°36.9´E		100	0
Elliott Heads	24°55.2´S, 152°29.6´E		79.8	20.2
Bargara (2nd Storm Drain)	24°48.9´S, 152°28.0´E	35.5	38.1	61.9
Bargara (N. of Bauer St.)	24°48.8´S, 152°27.8´E	35.7	47.1	52.9
Burnett Heads (middle)	24°46.1´S, 152°25.1´E		95.9	4.1
Burnett Heads (N. end)	24°45.7´S, 152°24.9´E		69.5	30.5
Turkey Beach	24°04.4´S, 151°39.1´E		100	0
Parsons Pt	23°51.2´S, 151°17.4´E		100	0
Emu Pt	23°15.5´S, 150°50.0´E	34.4	76.0	24.0
S Cooee Bay	23°08.5´S, 150°45.7´E	35.5	76.0	24.0
Fishermans Beach	23°08.5´S, 150°45.7´E	35.2	87.8	12.2
Clairview	22°07.0´S, 149°32.2´E		100	0
Zelma Beach	21°21.6´S, 149°18.7´E		89.6	10.4
S Hay Pt	21°17.8´S, 149°17.6´E		85.3	14.7
Dudgeon Pt	21°14.8´S, 149°15.2´E		84.6	15.4
Slade Bay	21°04.3´S, 149°13.1´E		100	0
Mast (Slade Pt)	21°03.9´S, 149°13.4´E		100	0
Dolphin Heads	21°02.0´S, 149°11.1´E		89.3	10.7
St Helens Beach	20°49.4´S, 148°50.2´E		23.3	100
Midge Pt	20°38.9´S, 148°43.6´E	32.2	93.7	6.3
Tooloakea	19°08.7´S, 146°34.9´E	28.8	100	0

3, arrows A) as well as large, irregular catchment scale flooding (Fig. 3, arrow B). During the latter event, Coates (1992) found that salinities less than 15‰ persisted on rocky shores in that area for up to 13 days. In addition, it can be seen by inspection of Figure 3, that low salinities can coincide with peak summer temperatures, resulting in the combined stress of low salinity and high temperature.

Sampling over time at a site with no freshwater influence and a site influenced by fresh water showed that *C. taeniatus* had a low relative abundance at the former, where *C. virescens* dominated, but had a high relative abundance at the latter. Field surveys along the Queensland coast found that in intertidal areas along the open coast, with no freshwater influence, *C. virescens* was highly abundant while *C. taeniatus* was in low abundance, or absent. However, at sites influenced by freshwater flows there were high relative abundances of *C. taeniatus*.

On the basis of the present study we suggest that *C. taeniatus* is adapted to intertidal areas which experience some freshwater flow over the long term. *Clibanarius virescens*, on the other hand, although intolerant of fresh water, dominates over *C. taeniatus* in areas without freshwater influence. Further research is required to determine why *C. virescens* is dominant in areas without freshwater influences. In addition to freshwater, factors such as differences in feeding behaviours and the availability of food sources may also play very important roles in affecting the large scale distribution of *C. taeniatus* and *C. virescens*. Kunze and Anderson (1979) found that these particular species had slight differences in their feeding mechanisms. They reported that *C. taeniatus* is predominantly a soft food detritivore, while *C. virescens* is both detritivorous and macrophagous and uses the chelae and crista dentata for trituration. *Clibanarius taeniatus* does not appear to use the chelipeds to tear *Zostera* sp. seagrasses apart, unless the tissue is decayed and already breaking down. Instead, this species uses the chelipeds to scrape epiphytic algae from the laminae of *Zostera* sp. (Kunze and Anderson, 1979). The geographical distribution of *C. taeniatus* and *C. virescens* may also be affected by the ability of larval recruits to detect, avoid or survive low salinity waters. It has become increasingly clear that the larvae of a great many marine invertebrates are not only able to discriminate between favourable and unfavourable habitats (Levinton, 1995; Willmer et al., 2000 and see review by Morgan, 1995), but are also able to delay metamorphosis under unfavourable conditions (see review by Crisp, 1976).

In areas experiencing increased freshwater influence it is expected that there will be an increase in the relative abundance of *C. taeniatus* and a concomitant decrease in the relative abundance of *C. virescens*. These species therefore constitute a useful indicator system of new, long-term sources of freshwater inundation, whether natural or anthropogenic, in intertidal areas.

Intertidal hermit crabs are relatively easy to sample and identify in the field and are common in tropical intertidal areas. With increased residential and commercial development in tropical coastal areas, storm water runoff has the potential to act

as a "pollutant" in intertidal areas. The presence of an easy to use indicator system, such as the one described here, constitutes a valuable tool for managers responsible for the well being of coastal areas. It would be most interesting to trial this system by monitoring the site of a proposed coastal development where *C. virescens* is highly abundant, both prior to and after the introduction of storm water drains.

There is evidence that other pairs of hermit crab species in other areas have similar distribution patterns to *C. taeniatus* and *C. virescens* (Ball and Haig 1974; Abrams 1980; Bertness 1981; Gherardi and Nardone 1997; Barnes 1997; Turra and Leite 1999). We suggest that it would be worthwhile to determine if such similarly distributed pairs of hermit crab species would also constitute indicator systems on other tropical coasts where there is a potential threat from residential storm water runoff.

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